Targets

The experimental targets are ^{12}C, ^{116}Sn, and ^{208}Pb, each with thickness 5% of a radiation length. Details of the targets are given in the table below.

Target	Thickness (mil)	$r\ t\ (mg/cm^2)$	Isotopic purity (%)
^{12}C	370	2100	98.9
^{116}Sn	24	440	95.7
^{208}Pb	11	330	99.9

These specific isotopes were chosen because they are even-even nuclei ($J^p = 0^+$ ground state) and the ground state charge densities have been measured in model-independent-analyses of electron scattering data. Accurate knowledge of the charge density minimizes the uncertainty in the Primakoff vertex due to the charge form factor.

Charge density references

^{12}C charge density: L.S. Cardman et al., Phys. Lett. 91B, 203 (1980), W. Reuter, et. al., Phys. Rev. C26, 806 (1982), and I. Sick, Phys. Lett. 116B, 212 (1982);

^{116}Sn charge density: J.M. Cavedon, et. al., Phys. Lett. 118B, 311 (1982);

^{208}Pb charge density: B. Frois, et. al., Phys. Rev. Lett. 38, 152 (1977), and H. Euteneuer, et. al., Nucl.Phys. A298, 452 (1978).

Measuring target thickness

In this experiment it is necessary to have uncertainties in $r\ t$ at the level of $\pm 0.7\%$ or better. Oak Ridge estimates the uniformity in thickness of the rolled metal targets is at the level of $\pm 1\%$ to 2%, except near the target edges where the thickness drops off. Therefore we plan to use oversize targets (2.5 cm by 2.5 cm) and map target thickness as a function of position on the target. Since the photon beam spot at the target is approximately 2 mm in diameter, the targets can be positioned such that the photon beam strikes a region with known, uniform thickness.

The required tolerance on the target thickness can be achieved using a micrometer. For example, Mitutoyo (http://www/mitutoyo.com/micrometers.html) makes a digital micrometer with an accuracy of ± 0.05 mil. The table below shows the estimated target thickness uncertainty obtained using a micrometer with accuracy ± 0.05 mil.

Target	**Thickness (*mil*)**	**Percentage uncertainty if measured to ± 0.05 mil**	**Density (g/cm^3)**
^{12}C	370	.014%	1.9-2.3
^{116}Sn	24	.21%	7.31
^{208}Pb	11	.46%	11.35

The limiting factor for the carbon target is non-uniformity in density. Because of the fragility of the metal targets we plan to use a measurement technique that doesn't involve touching the targets and provides a direct measurement of $r\ t$. This method uses x-ray attenuation to measure $r\ t$.

In this technique a line source of x-rays is collimated down to a spot size a few mm in diameter and detected in a NaI detector. The experimental targets are placed as absorbers between the source and the detector. By measuring the ratio of x-ray flux in the NaI detector for target-in to target-out the ratio $r\ t/l$ can be determined, where l is the x-ray absorption length. Since the x-ray absorption lengths are only known to the level of a few percent, we calibrate the measurement by taking x-ray absorption data on a calibration plate of the same material with known thickness.

Best precision is obtained using an x-ray with energy such that the x-ray absorption length l is approximately $r\ t/2$. For both the Sn and Pb targets these energies are approximately 60 keV. Therefore, a good choice for both the Sn and Pb targets is the 60 keV x-ray line from ^{241}Am.

Target	$r\ t$ (mg/cm^2)	l @ 60 keV (mg/cm^2)
^{116}Sn	440	152
^{208}Pb	330	199

The calibration plates should be thick enough to limit thickness uncertainties from micrometer accuracy, robust enough to be handled with a micrometer, and with thickness not so very different than $2m$. Therefore we plan to use calibration plates of natural isotopic abundance materials that are approximately twice the thickness of the experimental targets, 50 mil for Sn and 20 mil for Pb.

Let R_0, R_T, and R_C equal the ^{241}Am 60 keV x-ray rates in the NaI without absorber, with the target absorber, and with the calibration plate absorber, respectively. The target thickness T is given by

$$T = C\frac{\ln(R_0/R_T)}{\ln(R_0/R_C)}$$

where C is the calibration plate thickness in units of g/cm^2. The error in the target thickness measurement is given by

$$\left(\frac{s_T}{T}\right)^2 = \left(\frac{s_C}{C}\right)^2 + \left[\frac{1}{\ln(R_0/R_T)}\right]^2 \left(\frac{s_{R_T}}{R_T}\right)^2 + \left[\frac{1}{\ln(R_0/R_C)}\right]^2 \left(\frac{s_{R_C}}{R_C}\right)^2 + \left[\frac{1}{\ln(R_0/R_T)} - \frac{1}{\ln(R_0/R_C)}\right]^2 \left(\frac{s_{R_0}}{R_0}\right)^2$$

Evaluating the above expression for 60 keV x-rays on Sn and assuming a measurement tolerance of ± 0.05 mil gives

$$\left.\frac{s_T}{T}\right|_{Sn} = \sqrt{10^{-6} + \frac{0.119}{N_T} + \frac{0.0298}{N_C} + \frac{0.0298}{N_0}}$$

where N_T, N_C, and N_0 are the total counts for target absorber, calibration absorber, and no absorber. The same assumptions for the Pb target gives

$$\left.\frac{s_T}{T}\right|_{Pb} = \sqrt{6.25\times 10^{-6} + \frac{0.364}{N_T} + \frac{0.0909}{N_C} + \frac{0.0909}{N_0}}$$

Assuming that errors from N_C and N_0 are negligible, then approximately 2,500 counts are required for Sn and 8,500 counts for Pb to measure $r\ t$ at the level of 0.7%. For a source intensity of $R_0 = 1$ Hz the required count time is 12.5 hours for both Sn and Pb.

The limiting factor in measuring the ^{12}C target is the graphite density, which must be homogeneous and known to a level of better than $\pm 0.7\%$. This is a requirement that will be difficult to meet because of density variations in graphite. For this reason we propose to use an x-ray energy where the x-ray absorption coefficient is known to an accuracy of better than $\pm 0.7\%$. For example, compilations of the absorption coefficient on ^{12}C at 40 keV have varied by only $\pm 0.5\%$ over the past 30 years. If one averages measurements of the coefficient over this time period the standard deviation of the mean is $\pm 0.4\%$.

If the absorption coefficient is known then the target thickness is given by

$$T = l\ \ln\left(\frac{R_0}{R_T}\right)$$

and the error in the target density is given by

$$\left(\frac{s_T}{T}\right)^2 = \left(\frac{s_l}{l}\right)^2 + \left[\frac{1}{\ln(R_0/R_T)}\right]^2 \left[\left(\frac{s_{R_T}}{R_T}\right)^2 + \left(\frac{s_{R_0}}{R_0}\right)^2\right]$$

Evaluating the error for a 40 keV x-ray gives

$$\left.\frac{s_T}{T}\right|_C = \sqrt{1.49\times10^{-5} + 5.27\left(\frac{1}{N_T} + \frac{1}{N_0}\right)}$$

To reach the needed precision requires 150,000 counts on ^{12}C. For a source intensity of $R_0 = 1$ Hz the required count time is approximately 60 hours.

Budget

The following items should be purchased with special funds designated for this experiment.

Item	**Cost**
^{116}Sn target	$6,776 (Lease option)
^{208}Pb target	$5,571 (Purchase)
Total	$12,347

We expect that the University of Massachusetts D.O.E. grant will pay for costs associated with target measurements. These costs include materials, ^{241}Am source, stepper motors, DAC card for PC, NaI crystal and tube, and precision micrometer. We will also expect that all of our machining needs, such as the graphite target, source holder, and the target frames, can be satisfied by the Physics Department machine shops where shop time is free.